

Off-axis-NOTE-SIM-0017

# Cross talk, Cracks and Inefficiencies: how do they degrade the physics potential of a detector ?

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## **Abstract**

We examine the effective loss of the physics detector as a result of 'reality factors' related to the imperfections of the detector.

# 1 Introduction

A real detector, once built, resembles the one conceived, if we are lucky. But even in the best case there are important differences: structural arguments, cable penetrations, HV and gas lines etc.. lead to various cracks. As the result some fraction of the detector volume has no active detector coverage, whereas some areas may have more dead materials than initially intended. In addition, realistic detectors are less than 100% efficient: in part due to an intrinsic inefficiency of the active detectors, in part due to inevitable, hopefully small, losses of detector coverage due to instrumental problems.

In this note we try to evaluate an effect of dead areas and detector inefficiencies on the physics reach of the experiment. In addition we examine the effect of a possible cross-talk between detector the neighboring strips.

# 2 The Method

We used a standard reconstruction and analysis procedure[1]. A figure of merit (FOM), defined as

$$FOM = \frac{signal}{\sqrt{background}}$$

is used to quantify the physics potential of a detector. This number depends on the detector parameters as well as on the unknown physics parameters. In this analysis a detector at a distance of 735 km from Fermilab and 10 km off axis was assumed. It was further assumed that  $\Delta_{23} = 0.0028 \text{ eV}^2$ ,  $\sin^2 2\theta_{13} = 0.05$  and  $\delta = 0$ . The FOM is computed assuming 250 kton-year exposure with 85% fiducial volume.

The data sets corresponding to "12 cm" detector are used as described in [2].

The background consists of several contributions: intrinsic  $\nu_e$  component of the beam, NC and CC  $\nu_\mu$  interactions. Dead areas and inefficiencies will, in general, lead to a loss of efficiency for signal events and to an increase of background, thus reducing the FOM. Given the fact that the FOM improves with the exposure as  $1/\sqrt{mass \times time}$ , a reduction of FOM due to detector imperfections is equivalent a certain loss of the fiducial mass. This loss can be expressed as

$$\Delta M = \left( \frac{FOM_R}{FOM_0} \right)$$

where  $FOM_0$  and  $FOM_R$  refer to a perfect and a realistic detector, respectively.

All the cuts are kept unchanged for all effects studied. This is the simplest case, but certainly not optimal. It corresponds to the case where one would ignore the detector imperfection in the analysis, even if they are known. In practice one should adjust the cuts or even the analysis strategy taking into account known dead areas and/or inefficiencies. Consequently, one should consider the results shown here as a conservative, worst case limit.

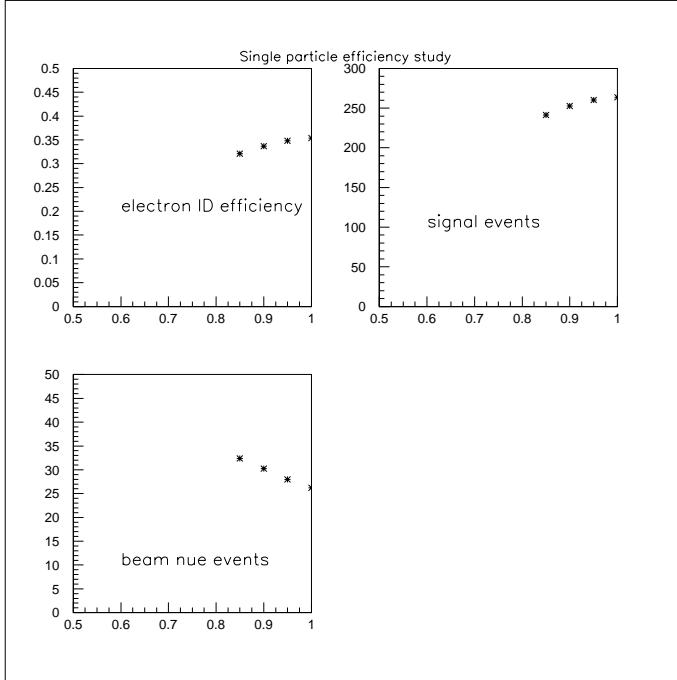


Figure 1: Top left: Efficiency for detection and identification of signal events ( $\nu_e$  interactions due to oscillations), as a function of a detector efficiency,  $\xi$ . Top right: Number of signal  $\nu_e$  events. Bottom left: Beam  $\nu_e$  background.

### 3 Detection inefficiency

Detection inefficiency may be a result of the intrinsic inefficiency of the active detector, fluctuation of the resulting signal etc.. We assume here that given a traversal of charged particle through the active detector volume we will register a 'hit' with a probability  $P = (1 - \epsilon) = \xi$ , where  $\epsilon$  is a detector inefficiency, and  $\xi$  is the detector efficiency. This inefficiency will be experimentally determined using cosmic muons and monitored throughout the running time of the experiment, thus it will not contribute in a significant fashion to the systematic error.

Fig. 1 shows a degradation of a signal efficiency with increasing detection inefficiency. The bottom plot shows that the corresponding number of background events due to  $\nu_e$  component of the beam is rising at the same time. This is related to the fact the the background events have in general higher visible energy than the signal ones, whereas the detector inefficiency is causing a systematic shift of the observed total energy due. This effect can and should be corrected thus reducing the size of the effect.

Fig. 2 shows that level of the NC and  $\nu_\mu$  CC background is very insensitive to the detector inefficiency. The resulting degradation of the overall FOM is a consequence of the reduction of the signal sample and an increase of the beam  $\nu_e$  background.

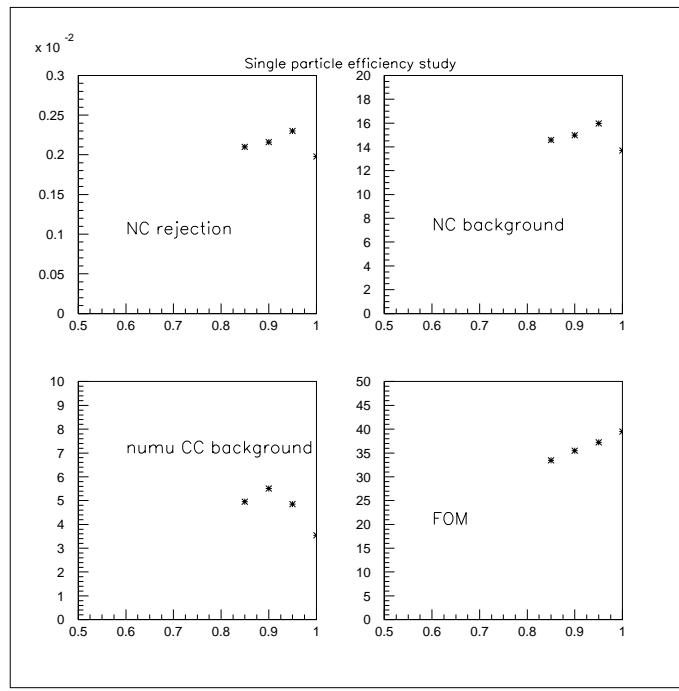


Figure 2: Top left: NC rejection event power as a function of a detector efficiency,  $\xi$  Top right: Number of background NC events Bottom left:  $\nu_\mu$  CC background. Bottom right: FOM

Loss of the effective fiducial mass of the detector as a result from the detection inefficiency is well parameterized by:

$$\frac{\Delta M}{M} = 1 - 2\epsilon$$

## 4 Cracks and dead spaces

The geometry of cracks and dead spaces depends on the details of the specific detector design. Proper analysis will require full GEANT simulation of a realistic detector. We have developed an approximate treatment here, assuming that the dead areas have similar material densities or that their relative contribution to the detector mass is rather small, thus the shower development in the realistic detector is well approximated by the shower development in the ideal simulated detector. Net effect of dead spaces can be therefore evaluated by ignoring the 'hits' occurring inside the dead areas.

### 4.1 Detector geometry

We assume a modular detector, the modules having transverse dimension  $2.4 \times 6 \text{ m}^2$ . It is assumed that the front and back wall of a module, if any, can be incorporated into the overall absorber geometry, hence they will not change the sampling frequency of the detector.

The principal contribution to the dead areas will come, therefore, from the top and bottom and side walls of the module (if any). We consider two exemplary cases:

- side walls and top and bottom walls have the same thickness
- top and bottom walls are 1 cm thick, whereas the side walls (load bearing ones) are thicker.

### 4.2 A detector with uniform walls

Fig. 3 shows a degradation of a signal efficiency as a function of the wall thickness  $t$ . Notice that the real dead space is  $2t$  thick in a stacked detector. The bottom plot shows that the corresponding number of background events due to  $\nu_e$  component of the beam is fairly constant. This is probably an interplay of a reduced electron identification efficiency and the down-feed of higher energy events loosing some of their energy in un-sampled regions. In this analysis we treat all events on equal footing. In a real experiment one would adjust the cuts to take into account cracks and dead spaces, thus the effects should be somewhat smaller.

Fig. 4 shows that the level of the NC and  $\nu_\mu$  CC background does not increase appreciably as a result of dead spaces. The reduction of the resulting FOM is primarily due to the loss of the signal events. We observe that loss of the FOM due to the wall thickness is rather small for thicknesses  $t \leq 3 \text{ cm}$ .

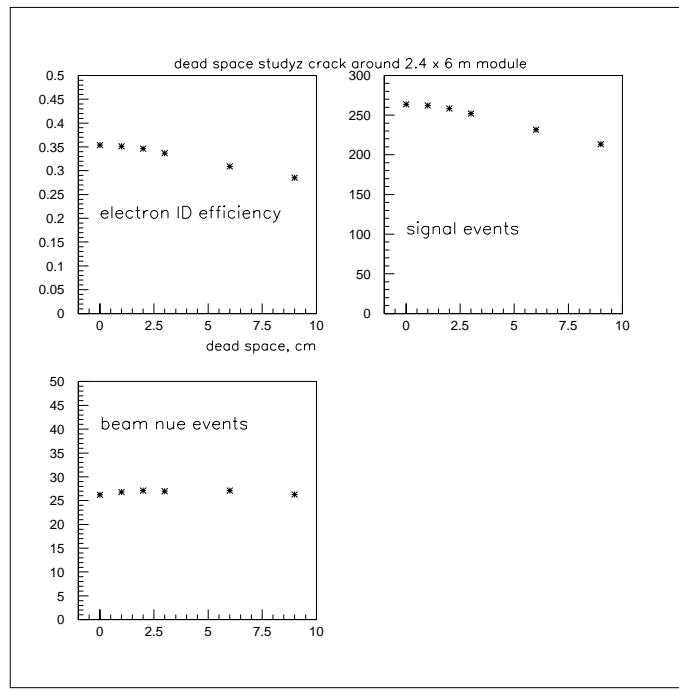


Figure 3: Top left: Efficiency for detection and identification of signal events ( $\nu_e$  interactions due to oscillations), as a function of a module wall thickness in cm. Top right: Number of signal  $\nu_e$  events Bottom left: Beam  $\nu_e$  background .

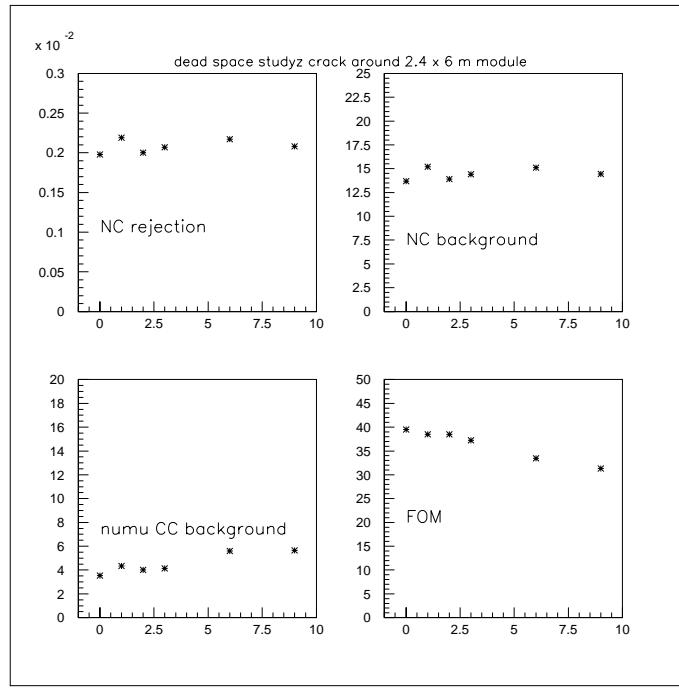


Figure 4: Top left: NC rejection event power as a function of a module wall thickness in cm. Top right: Number of background NC events. Bottom left:  $\nu_\mu$  CC background. Bottom right: FOM

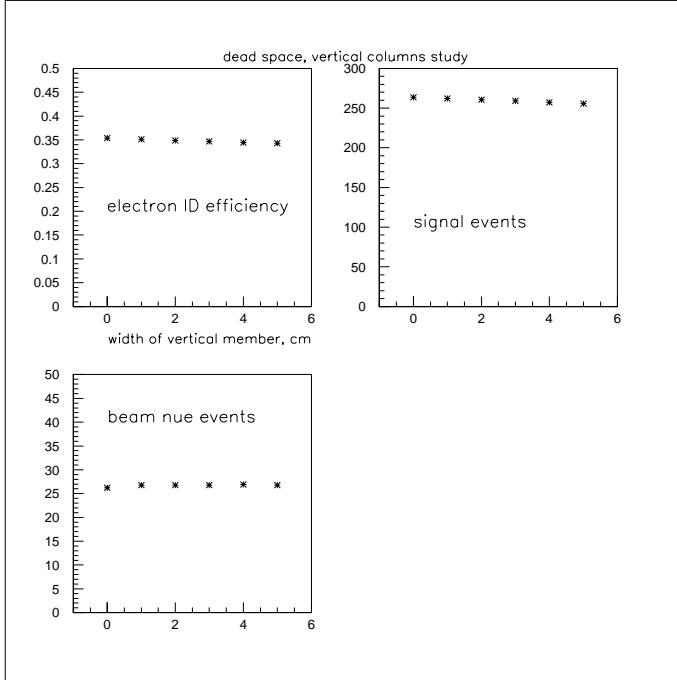


Figure 5: Top left: Efficiency for detection and identification of signal events ( $\nu_e$  interactions due to oscillations), as a function of a vertical module wall thickness in cm. Top right: Number of signal  $\nu_e$  events Bottom left: Beam  $\nu_e$  background.

### 4.3 A detector with structural vertical walls

In this geometry the load of the entire detector is transferred to the floor through the vertical (side) walls, referred to in the following as columns, while the top and bottom walls of a module are kept at a thickness of 1 cm.

Fig. 5 shows a degradation of a signal efficiency as a function of the column thickness  $t$ . Notice that the real (vertical) dead space is  $2t$  thick in a stacked detector. The bottom plot shows that the corresponding number of background events due to  $\nu_e$  component of the beam is fairly constant. This is probably an interplay of a reduced electron identification efficiency and the down-feed of higher energy events loosing some of their energy in un-sampled regions. In this analysis we treat all events on equal footing. In a real experiment one would adjust the cuts to take into account cracks and dead spaces, thus the effects should be somewhat smaller.

Fig. 6 shows that the level of the NC and  $\nu_\mu$  CC background does not increase appreciably as a result of dead spaces. The reduction of the resulting FOM is primarily due to the loss of the signal events. We observe that loss of the FOM due to the column thickness is very small event for thicknesses approaching  $t \sim 5 - 6$  cm. The smallness of the effect, in comparison with the previous case comes from the fact that the columns are much shorter than the top/bottom walls, hence at the given wall thickness they contribute much less to the fraction of dead material.

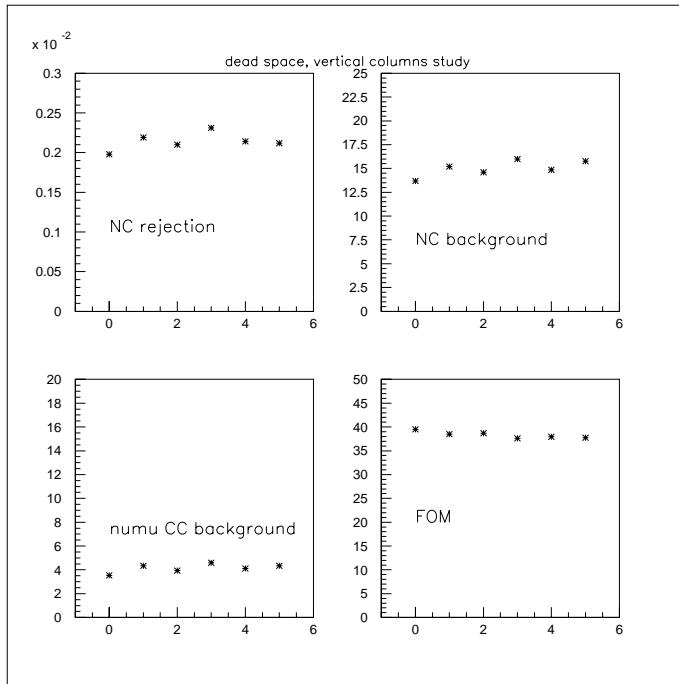


Figure 6: Top left: NC rejection event power as a function of a vertical module wall (column) thickness in cm. Top and bottom walls of the module are assumed to have a thickness of 1 cm. Top right: Number of background NC events Bottom left:  $\nu_\mu$  CC background. Bottom right: FOM

## 5 Cross-talk

Neighboring strips of the detector may exhibit 'cross-talk', i.e. a strip may produce with a certain probability a signal even if particle traversed only the neighboring strip. This cross talk may have an electronics contribution, independent of the actual position of the charged track within the strip and the 'physical' contribution caused by the sharing of the produced signal for particles passing in between two strips.

We ignore this distinction and parameterize the cross talk in terms of a  $\chi$ , the cross-talk probability averaged over the strip. This probability, as well as the degradation of the FOM, will depend on the actual strip width. In this study we have assumed 3 cm wide strips, the effects will be reduced considerably for wider strips.

Fig. 7 shows an evolution of a signal efficiency as a function of the cross talk probability  $\chi$ .

The bottom plot shows the corresponding number of background events due to  $\nu_e$  component of the beam. In contrast to the case of inefficiency or dead spaces this background is reduced in the presence of the cross talk. The underlying reason, higher energy of the background events, is the same but the sign of the effect is inverted here. Higher energy events have more hits, they produce more 'spurious' hits, hence their total energy appears even higher.

Fig. 8 shows that the level of the NC and  $\nu_\mu$  CC background as a function of the cross-talk probability. Again, the situation is very different from the dead space case. Cross-talk increases the multiplicity of hits per track, thus it makes pion and muon tracks more 'shower-like'.

Fig. 8 indicates that it is desirable to keep the average cross-talk probability  $\chi \leq 0.05$

## References

- [1] L. Camilleri, A. Para, The reconstruction of Numu and Nue Monte Carlo events, Off-axis Note-SIM-011
- [2] A. Para, RPC detector simulation using GMINOS, Off-axis Note-SIM-010

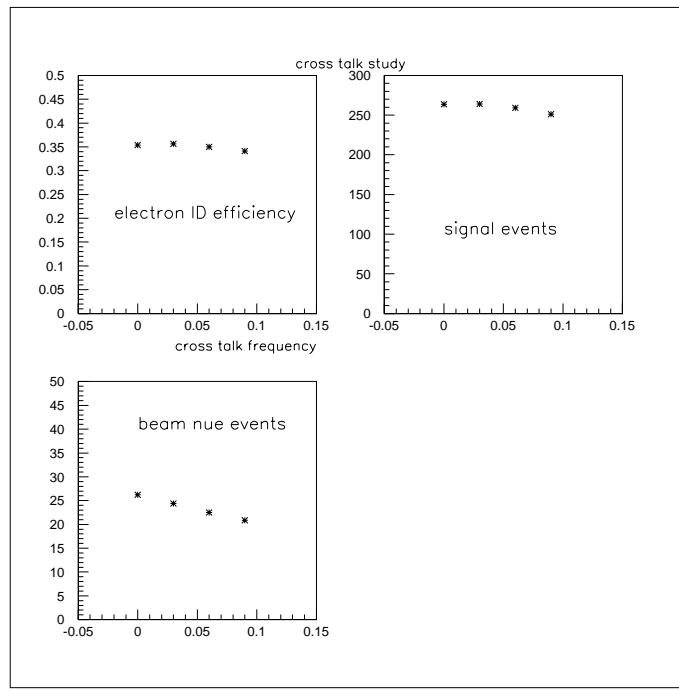


Figure 7: Top left: Efficiency for detection and identification of signal events ( $\nu_e$  interactions due to oscillations), as a function of a cross-talk probability  $\chi$ . Top right: Number of signal  $\nu_e$  events Bottom left: Beam  $\nu_e$  background.

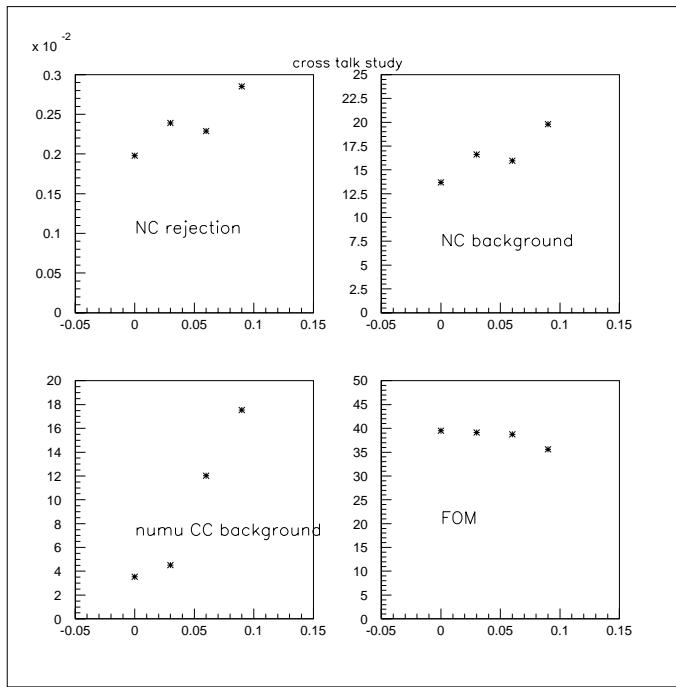


Figure 8: Top left: NC rejection event power as a function of a cross talk Top right: Number of background NC events Bottom left:  $\nu_\mu$  CC background. Bottom right: FOM